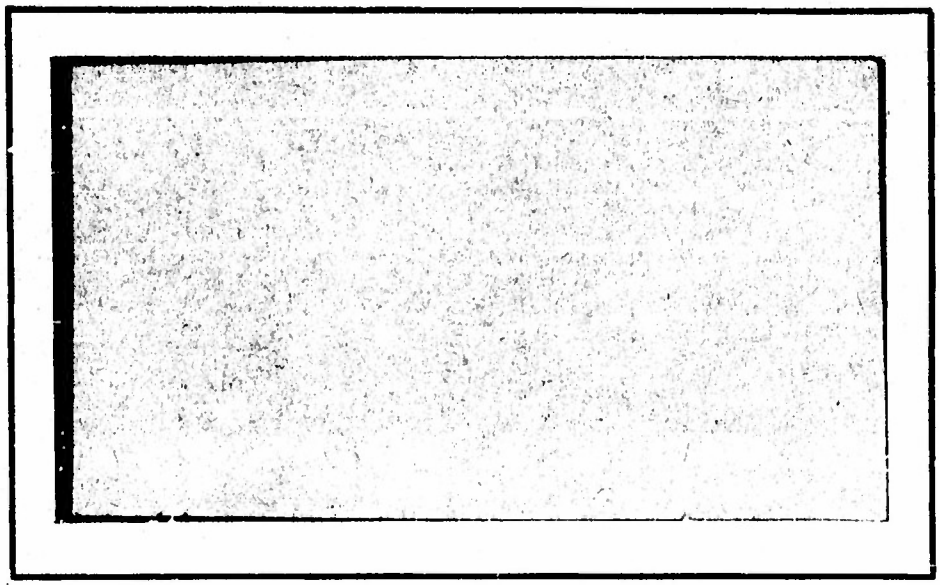

OFFICE OF NAVAL RESEARCH

and

ATOMIC ENERGY COMMISSION

Contract N6 ori-83, T. O. II

NR 024-022

Nuclear Physics Laboratory

UNIVERSITY OF NOTRE DAME

NOTRE DAME, INDIANA

NUCLEAR PHYSICS

TECHNICAL REPORT NO. 4

Energy Determination of Cs^{137} K Conversion Electrons

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Abstract

The electrostatic analyzer, previously used to determine the photo-thresholds of deuterium and beryllium, has been used to measure the energy of the K-conversion electrons from Cs^{137}. A value of 625.2 $\pm$ 0.9 Kev was obtained, in good agreement with the measurements of others.

I INTRODUCTION

In an accompanying report[1], a determination of the photodisintegration thresholds of deuterium and beryllium is described. These thresholds are obtained by measuring the energy of the electrons producing the bremsstrahlung with a cylindrical electrostatic analyzer. As a check on the energy scale of the analyzer, we decided to measure the energy of a well known electron line from Cs^{137}.

A 2.62 m Ba^{137} isomer results from the beta decay of Cs^{137}(37y). This isomer decays to the ground state by emission of a gamma ray of 661 Kev and internally converted electrons of 624 Kev. Langer and Moffat[2] measured the energy of the K internal conversion electrons by comparison with the K internal conversion electrons from Au^{198} using a 180° double-focussing magnetic spectrometer. They used the value of 411.8 Kev for the Au^{198} gamma ray as determined by DuMond, Lind and Watson[3] with a curved crystal spectrometer. Their result is 623.9 ± 0.7 Kev for the K electrons and 661.4 ± 0.7 Kev for the gamma ray after adding the K electron binding energy[4].

Muller, Hoyt, Klein and DuMond[5] measured the gamma ray energy of the Cs^{137} directly with a curved crystal spectrometer. Their result is 661.60 ± 0.14 Kev.

Lindstrom, Siegbahn and Wapstra[6] using a double focussing magnetic spectrometer, measured this gamma ray by comparison with K photo-lines from a uranium converter produced by a) annihilation radiation, and b) the 510.85 Kev gamma ray of ThC". With the same instrument the energy of the Cs^{137} K conversion electrons was determined by comparison with the conversion electrons of the previously mentioned ThC" line. The same authors measured the energy of the K conversion electrons of

the Cs^{137} in a small 180° magnetic spectrograph, calibrating the magnetic field with the proton resonance absorption. Their final result is 661.65 ± 0.15 Kev for the gamma ray and 624.21 ± 0.15 Kev for the K-electrons.

From these determinations one sees that the energy of the Cs^{137} K conversion electron is known to within 1 part in 4000. This is an excellent electron line to check our electrostatic analyzer which has an inherent accuracy of about 1 part in 1000.

II EXPERIMENTAL

The cylindrical electrostatic analyzer used in this experiment has been described in detail by Hoyes, Van Homissen, Miller and Waldman[1]. It is an absolute device having an accuracy of 0.1%. Honnold and Miller[7]* have developed the theory of this analyzer giving special attention to the effect of the small residual magnetic field.

Since this analyzer was used originally to analyze the electron beam of our electrostatic generator the following additional measurements and modifications had to be made for use as a spectrometer:

A the final detection slit had to be located accurately,

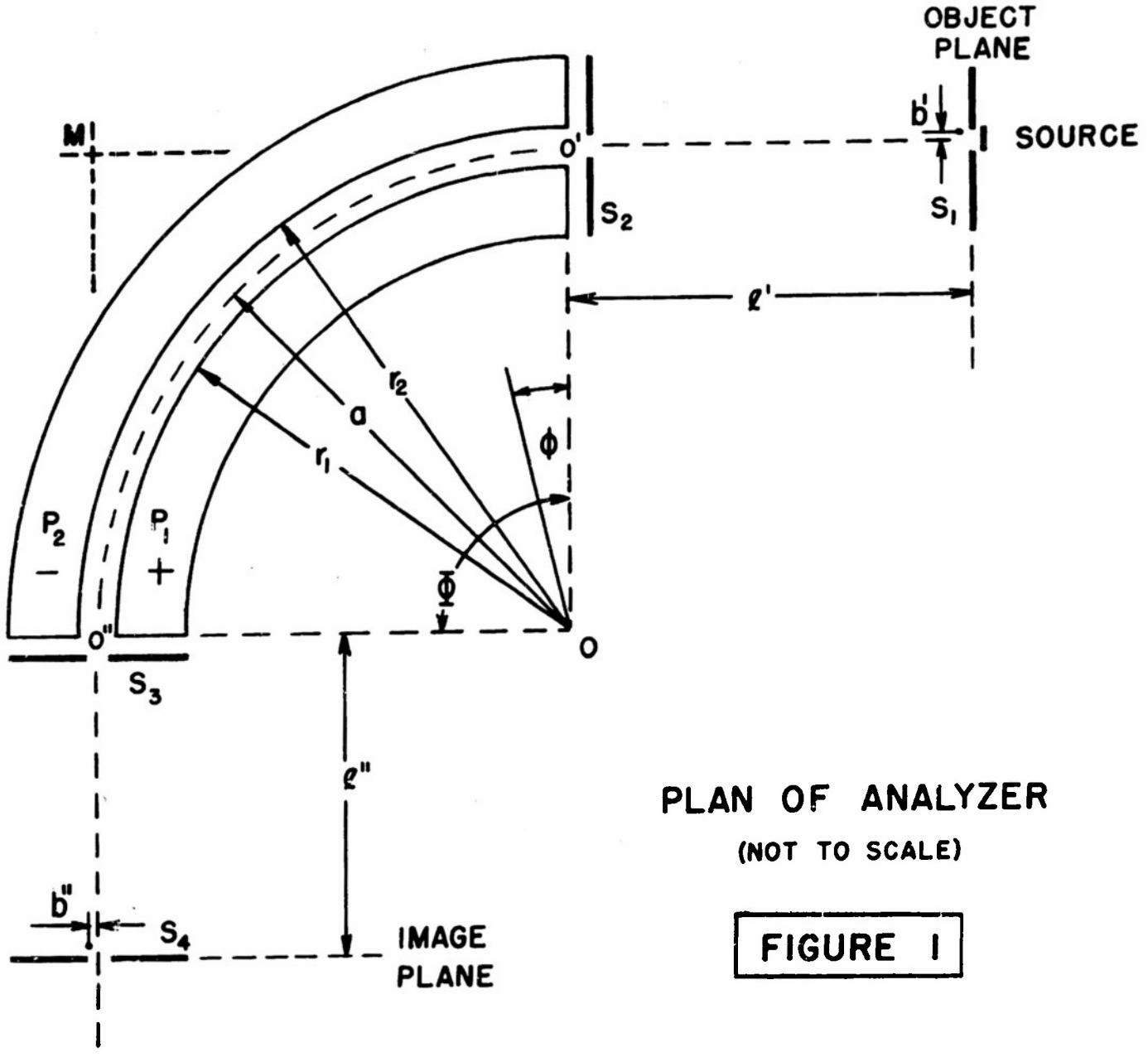
B the magnetic field in the entire region between source and detector had to be mapped,

C a suitable electron detection device had to be incorporated.

A Location of detection slit.

Fig. 1 is a plan of the analyzer. There are four pairs of beam and field defining slit systems. The object slit S_1 is in the object

*Cf. Accompanying Technical Report.



PLAN OF ANALYZER

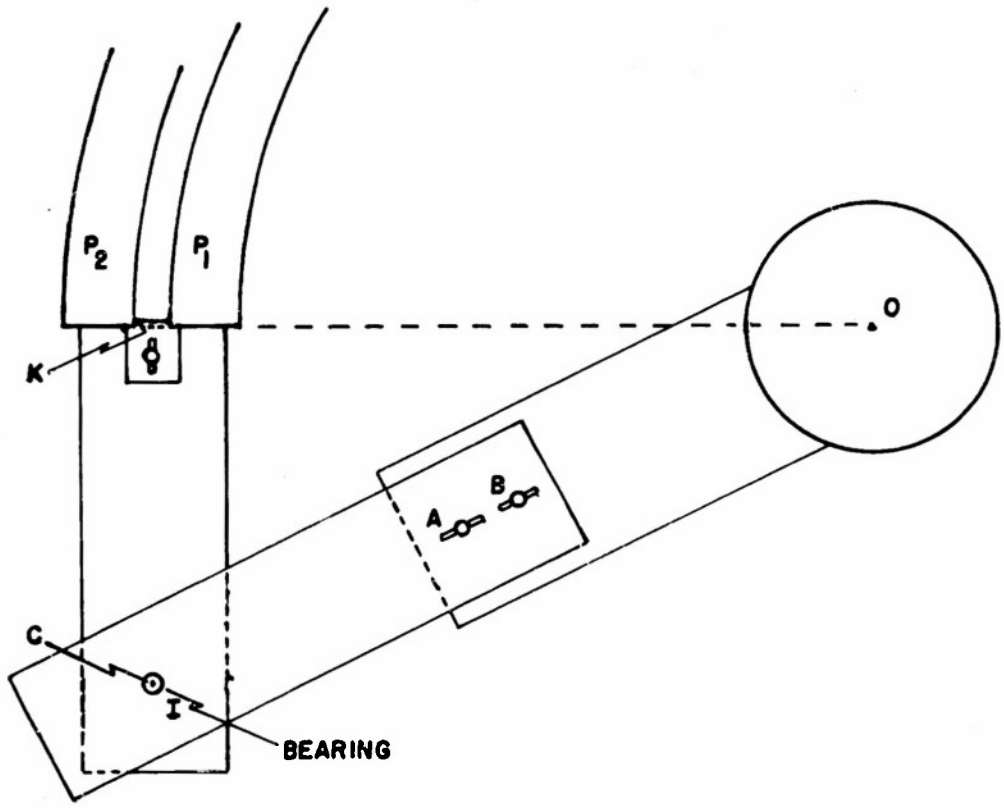
(NOT TO SCALE)

FIGURE 1

plane 30" from the entrance end of the analyzer. Slits S_2 and S_3, located at the entrance and exit ends of the analyzer, serve to limit the extent of the electric field. Herzog[8] has shown that for the gap width of 0.304", the fringe field at the ends of the analyzer can be considered zero if S_2 and S_3 have total widths of 0.150" and are spaced 0.060" from the plates P_1 and P_2. Slit S_4 is in the image plane located 11.3" from the exit end of the analyzer.

Since we plan to use this analyzer for further beta ray spectrometry, (necessitating frequent relocation of S_4 [7]) it was decided to scribe on the supporting surface plate lines tangent to the trajectory at S_2 and S_3. The arm indicated in Fig. 2 was attached to the precision bearing at the center of curvature O. The angle OCK was adjusted until the key K mated with the gap between plates P_1 and P_2. Thus an index rod through the center of the bearing C is on the tangent to the trajectory. By a system of fine plumb bobs and telescope this line was extended to the vicinity of M and a fine line was scribed on the surface plate. In like fashion, the other tangent line was located near M and the intersection of these lines locates the point M common to both tangents. We estimate the accuracy of the location of M to be $\pm$ 0.01".

The location of the slits S_1 and S_4 was accomplished by a telescope and plumb bobs erected at M and at either S_2 or S_3. It is of interest to note that this location of S_1 was identical (within the accuracy of our observation) with the original location determined by triangulation[1]. During the course of the experiment, slit S_4 was moved transverse to the trajectory in order to study the intensity distribution in the image plane. It was found that the maximum height



$$OK = 24.002''$$

$$KC = 12.000''$$

$$OC = \sqrt{(12.000)^2 + (24.002)^2}$$

FIG. 2 SLIT CENTERING

of the K peak occured when S_4 was located on the previously determined tangent line.

B Magnetic Field Mapping.

Noyes et al[1] measured the magnetic field in the electrostatic analyzer using a flip coil and ballistic galvanometer. Due to the limitation of the size of the flip coil the deflections were only a few millimeters. Consequently, the more sensitive peaking strip[9] method was used in this experiment.

A strip (1/16" x 3/8" x .005") of Delta-max was inserted into the center of a 1000 turn coil of #40 copper wire wound on a Lucite spool (0.40" x 0.15"). This probe was small enough to clear the plates of the analyzer and was mounted on the arm pivoted at O for the mapping between O' and O".

The probe, Fig. 3A, was used as one of the arms of the Maxwell bridge (Fig. 3B). The oscillator was a Hewlitt Packard 200-C and the detector was a Hewlitt Packard 300-A Wave Analyzer. It can be shown that any even order harmonic generated in such a probe is practically a linear function of the external magnetic field. Consequently, the oscillator was set at 5KC and the analyzer at 10KC. The bridge serves two purposes: 1) by first balancing the bridge with the probe in zero field and with the oscillator at 10KC, the second harmonic content of the oscillator (when set at 5KC) is negligible at the detector terminals; 2) because the Maxwell bridge is frequency independent (for linear elements) the bridge is nearly balanced at 5KC and thus does not saturate the detector.

This device was calibrated in the field of a standard solenoid for an oscillator voltage of 10 volts at 5KC. The calibration curve.

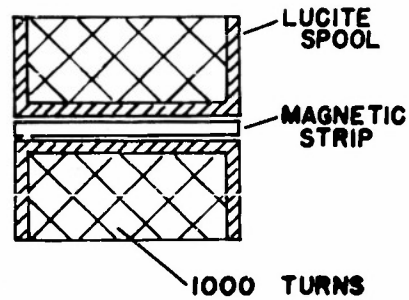


FIG. 3A PROBE UNIT

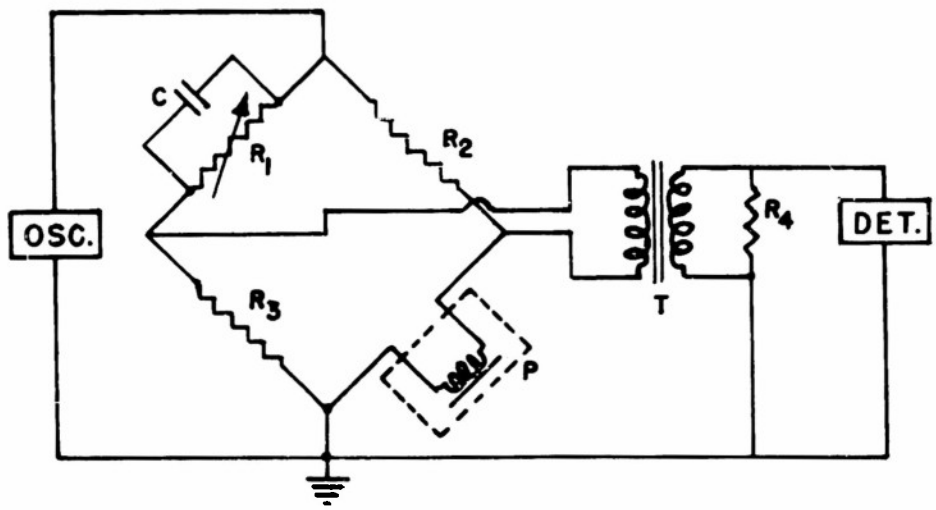


FIG. 3B BRIDGE CIRCUIT FOR MAGNETIC PROBE

OSC. = HEWLETT-PACKARD OSCILLATOR 200-C
DET. = HEWLETT-PACKARD WAVE ANALYZER 300-A
T = UTC TYPE O-1 LINE TO GRID

R_1 = 50K	R_4 = 50K
R_2 = 1K	C = 0.0047MF
R_3 = 1K	P = PROBE

Fig. 4, is linear up to 1.5 gauss (the largest field used) and has a slope of 5.6 milligauss/millivolt.

The direction of the magnetic field was determined by superposing a small field of known direction on the probe. An increase in output voltage indicates parallel fields, a decrease indicates antiparallel fields. This small field was obtained by a DC current (from a high impedance source to maintain bridge balance) through the coil of the probe.

The calibration was checked frequently by measuring the earth's magnetic field in a standard position near the analyzer. This field was measured with a Sensitive Research Fluxmeter and large flip coil. The distribution of the magnetic field in the regions between S_1 and S_2, between S_2 and S_3 (0^o to 90^o), and between S_3 and S_4 is shown in Fig. 5. These measurements agree with the preliminary measurements made by Noyes et al using the small flip coil and ballistic galvanometer.

Honnold and Miller have used these results in their analysis of the effect of this small residual magnetic field on the energy determinations made with this electrostatic analyzer. For the case of the Cs^{137} conversion electrons (ca 624 kev) the energy determined by the electric field alone must be decreased by 2.9 Kev.

C Electron Detection.

Due to the high source strength, a directional detector must be used to reduce the background. Preliminary experiments with two Geiger counters in coincidence proved satisfactory. A dual Geiger counter was machined from a brass block, details of which are shown

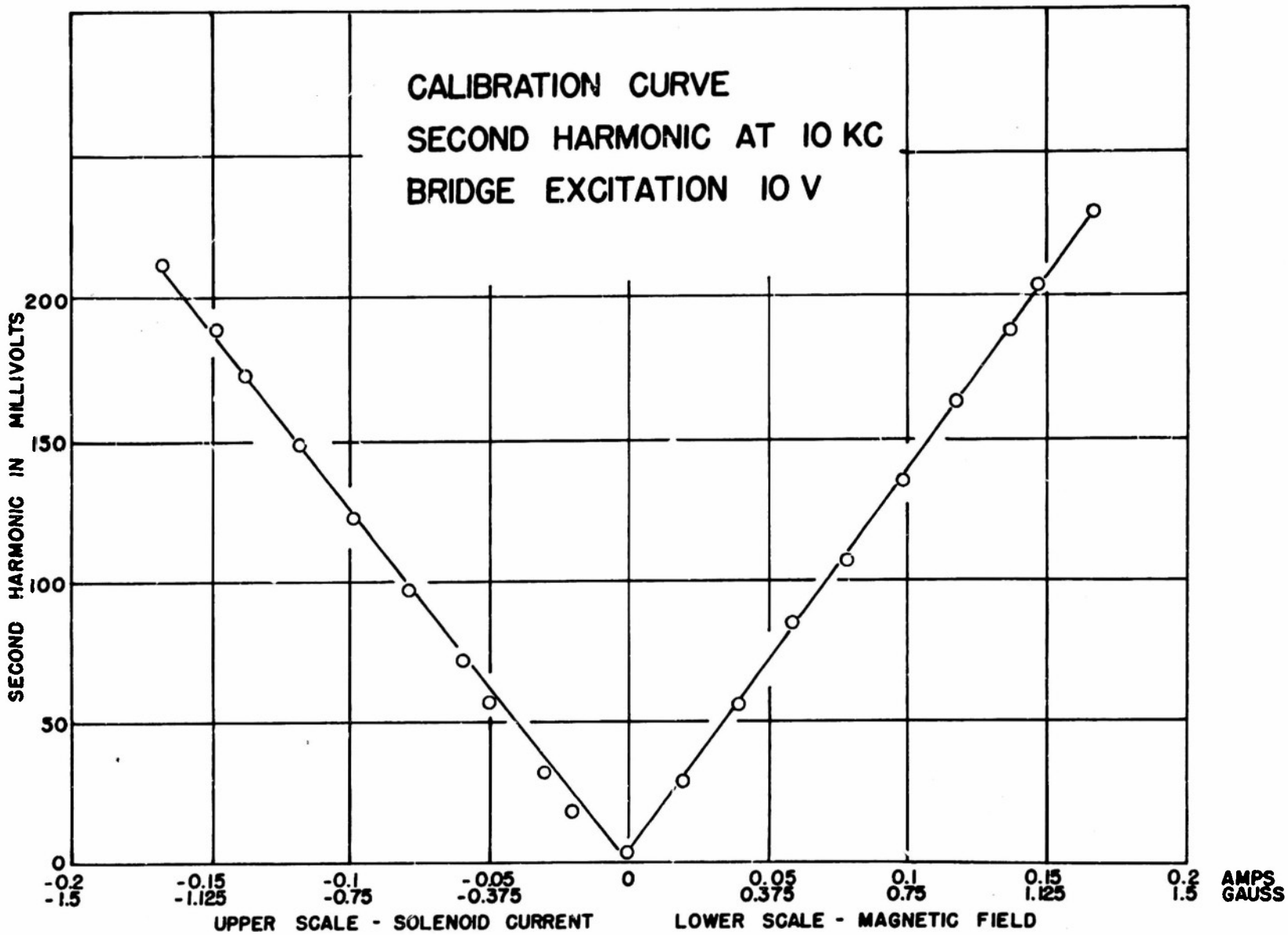

CALIBRATION CURVE
SECOND HARMONIC AT 10 KC
BRIDGE EXCITATION 10 V
SECOND HARMONIC IN MILLIVOLTS
200
150
100
50
0
-0.2
-1.5
-0.15
-1.125
-0.1
-0.75
-0.05
-0.375
0
0.05
0.375
0.1
0.75
0.15
1.125
0.2
1.5
AMPS
GAUSS
UPPER SCALE - SOLENOID CURRENT
LOWER SCALE - MAGNETIC FIELD

FIG. 4

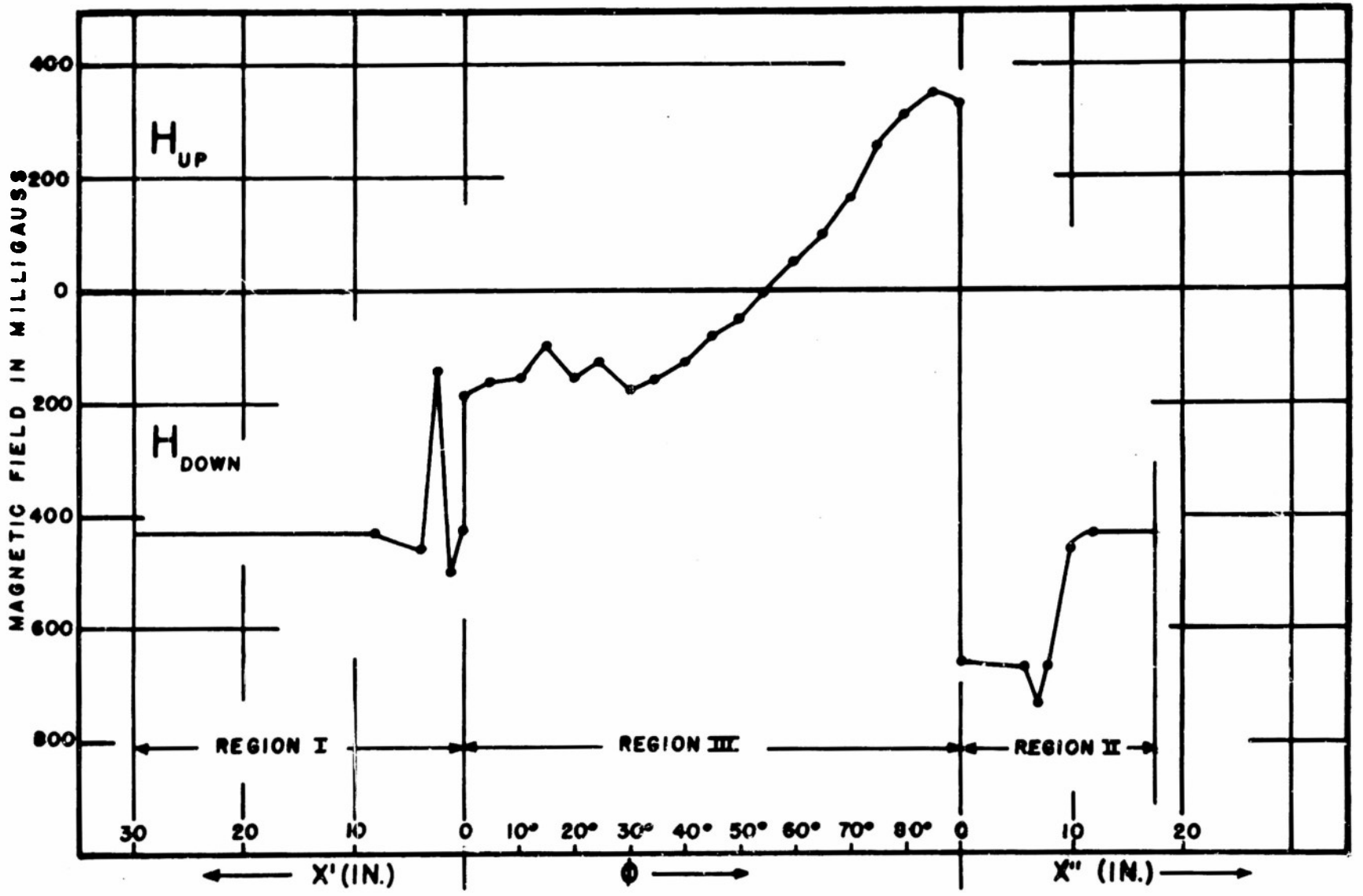


FIG. 5 MAGNETIC FIELD DISTRIBUTION

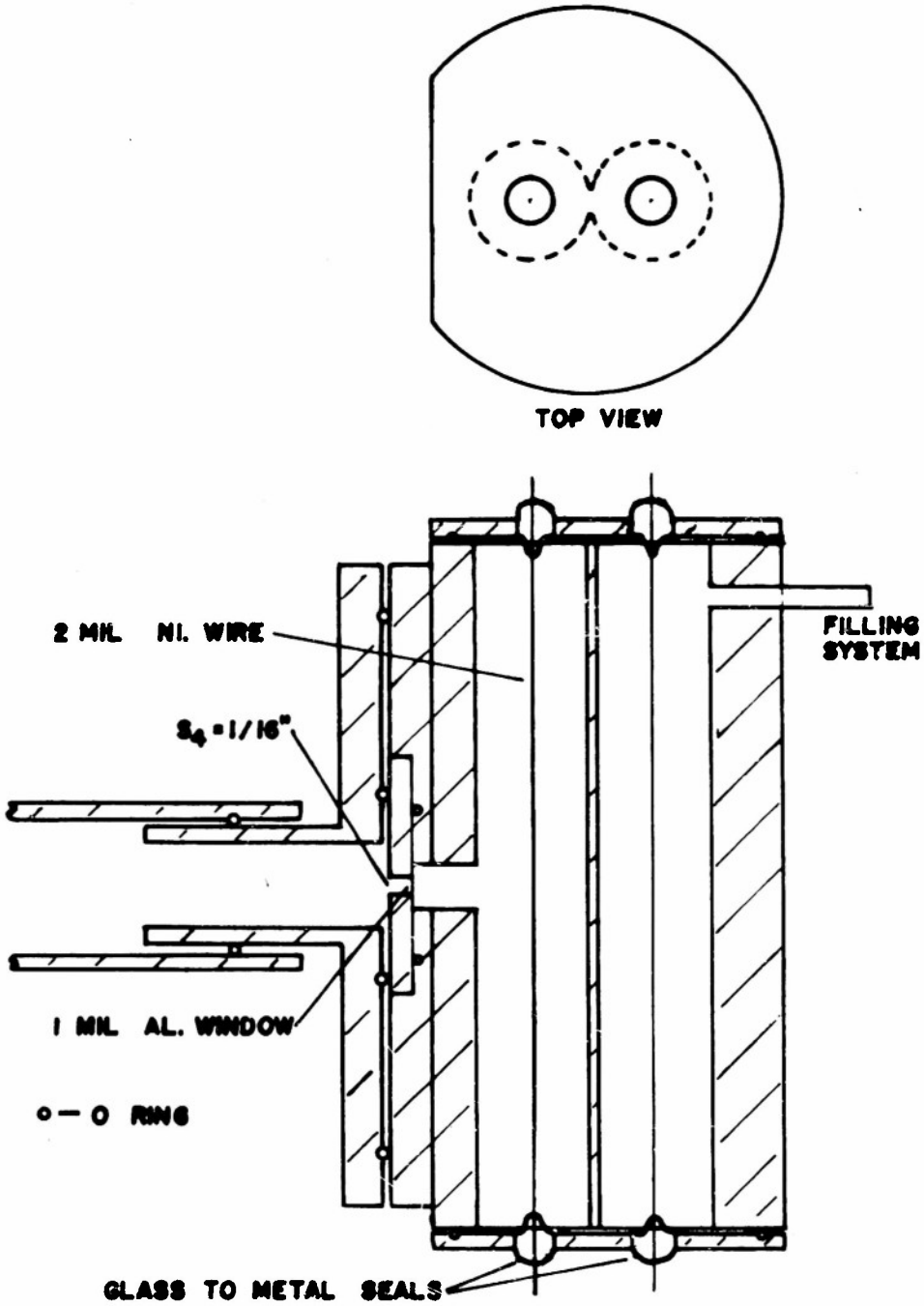


FIG. 6 COINCIDENCE COUNTER SYSTEM

in Fig. 6. The gas filling was the conventional argon-ethyl alcohol mixture. Both halves of the counter had the same characteristics and were operated at 1150 volts.

The coincidence background counting rate was 100 per 10 minute interval and remained constant throughout all the experiments.

D Source Preparation.

The electrostatic analyzer subtends a very small solid angle and consequently necessitates a strong source. The Cs^{137} that was procured from the Oak Ridge National Laboratory was in the chloride form in an HCl solution. The $CsCl_2$ was evaporated to dryness under a heat lamp, then dissolved in distilled water and re-evaporated to dryness. This process was repeated several times and resulted in the removal of the HCl. A few drops of the $CsCl_2$ in a distilled water solution were then permitted to evaporate on a 1 mil aluminum foil, first treating the foil with insulin to promote even spreading[10]. The source was 0.04" x 0.5" in size to correspond to slit S_1 and of approximately 2 to 3 millicuries strength. The source, on its aluminum foil backing, was mounted directly behind slit S_1 and grounded electrically to avoid charging effects.

III RESULTS AND DISCUSSION

Fig. 7 is a plot of the net coincidence rate versus potentiometer reading of voltage across the electrostatic analyzer plates. Slits S_2 and S_3, which act as guard slits at the entrance and exit of the analyzer, were set at 0.15", a value which made the fringe field zero.

In order to obtain greater intensity slits S_2 and S_3 were widened to 0.20". Fig. 8 is a plot of the data. The increased

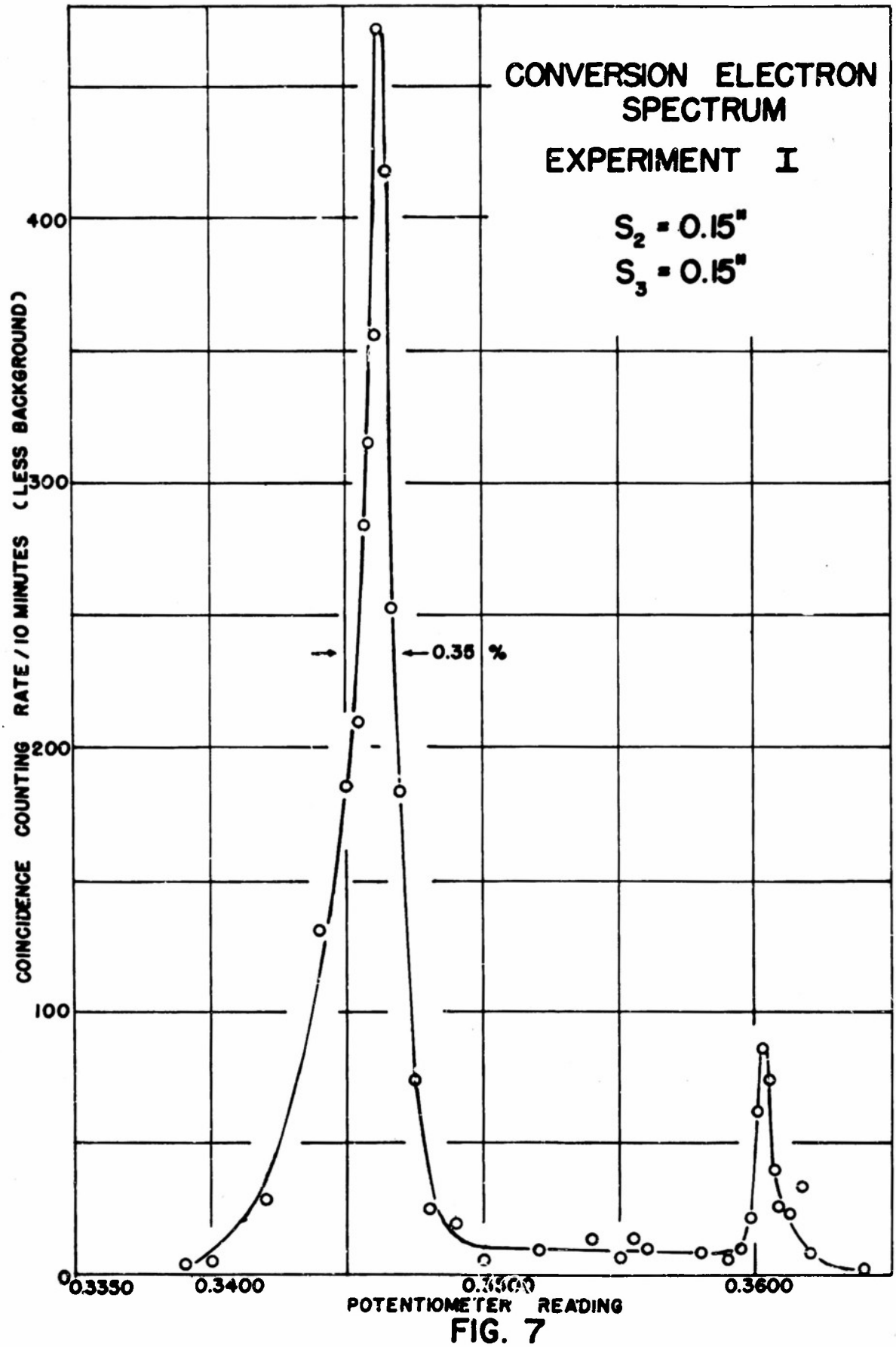

CONVERSION ELECTRON SPECTRUM
EXPERIMENT I
S_2 = 0.15"
S_3 = 0.15"
0.35 %
COINCIDENCE COUNTING RATE / 10 MINUTES (LESS BACKGROUND)
0
100
200
300
400
0.3350
0.3400
0.3500
0.3600
POTENTIOMETER READING

FIG. 7

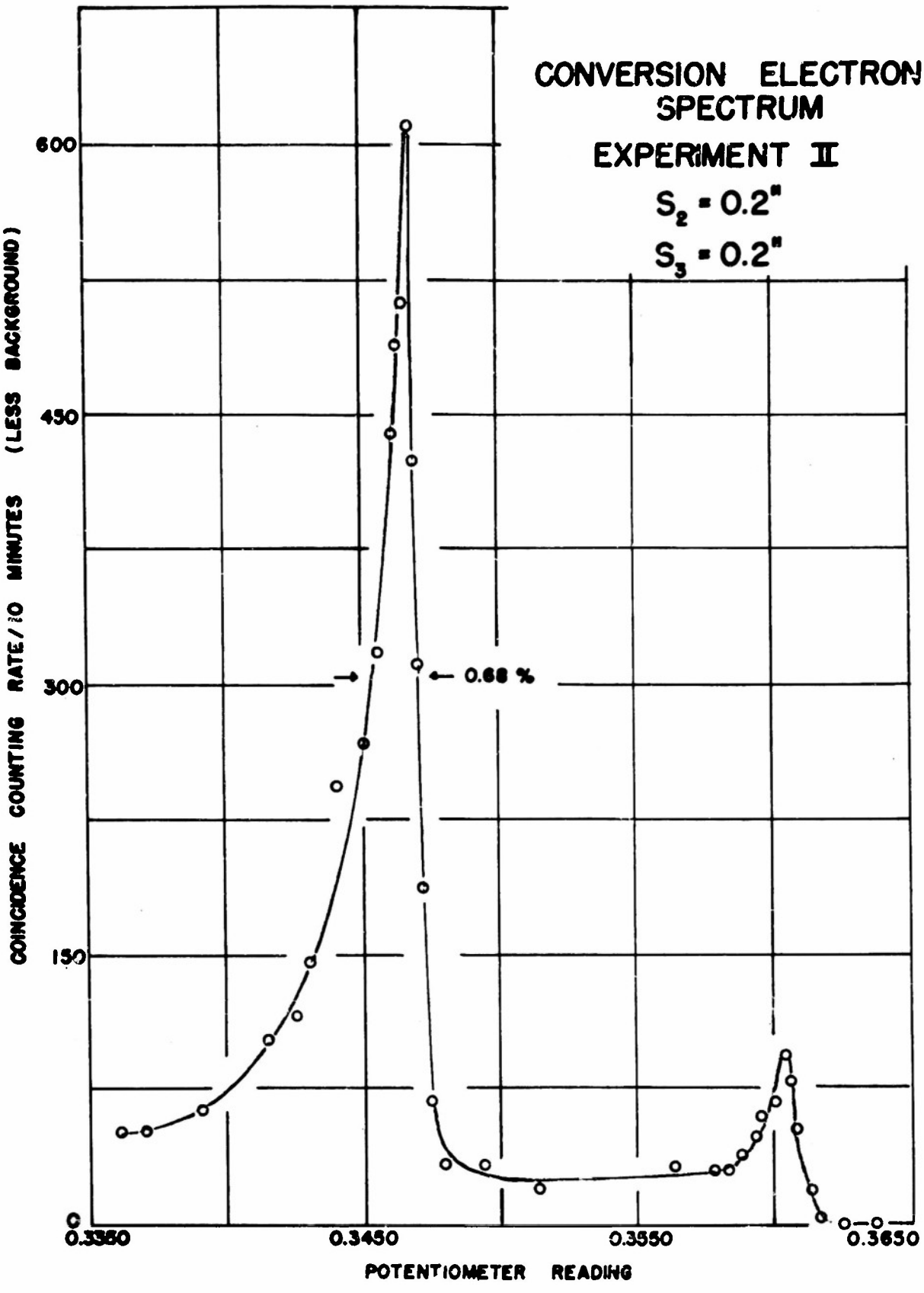

CONVERSION ELECTRON SPECTRUM
EXPERIMENT II
S_2 = 0.2"
S_3 = 0.2"
600
450
300
150
0
COINCIDENCE COUNTING RATE/10 MINUTES (LESS BACKGROUND)
0.68 %
0.3360
0.3450
0.3550
0.3650
POTENTIOMETER READING

FIG. 8

width of S_2 and S_3 resulted in an increased analyzer angle but this correction is too small to be considered. It also reduced the resolution of the analyzer which is evident from the curves.

Since the sources were relatively thick, the high energy edges of the lines were extrapolated to the abscissae. The potentiometer readings measure the voltage across the analyzer plates and can be converted into the energy of the electrons by eq. (2b) of Honnold and Miller. Table 1 gives the results of the K and L line energies as determined above.

The energy resolution of the analyzer for the slit widths used can be calculated from eq. (31) of Honnold and Miller. For the K line of Cs^{137} it is 0.9 Kev. This means the energy spread admitted by the last slit (S_4) is $\pm$ 0.9 Kev and is the limiting factor in determing the accuracy of this experiment.

The L lines were not resolved from the M lines in either experiment I or II, so that the energy determinations were made by extrapolating the high energy edge of the L peaks at their half-widths. As stated earlier, the slit-width of S_2 and S_3 in experiment II had an effect of increasing the fringe field and hence of effectively increasing the analyzer angle. This amounts to a correction of less than a tenth of a kilovolt. Therefore, arithmetic means were taken for the K-electron and L-electron energies corresponding to these two experiments. The difference between E_K and E_L is 31.10 Kev and is to be compared to the binding energy difference between the K and L shells of Ba^{137}. From the data of Hill, Church & Mihelich[4] this is 31.44 Kev. Table 2 lists the results of this investigation along with those of other workers.

TABLE I

Experimental energy values of K and L lines of Cs^{137}

Exp.	Line	Potentiometer Reading	Electron Energy (Kev)	Average Electron Energy (Kev)	Magnetic Field Correction (Kev)	Corrected Electron Energy (Kev)	K&L Llectron Binding Energies (Kev)	Gamma Ray Energy (Kev)
I	K	0.3465	627.77	628.10	2.90	625.2	37.43	662.6
II	K	0.3468	628.44					
I	L	0.3606	658.72	659.06	2.80	656.3	5.99	662.3
II	L	0.3610	659.41					
						Diff = 31.10	Diff = 31.44	

TABLE II

Reference	K-Conversion electron energy (Kev)	Gamma ray energy (Kev)
Langer & Moffat[a]	623.9 ± 0.7	661.4 ± 0.7
Muller, Hoyt, Klein & DuMond		661.60 ± 0.14
Lindstrom, Siegbahn & Wapstra	624.21 ± 0.15	661.65 ± 0.15
Present Investigation	625.2 ± 0.9	(662.6 ± 0.9)[b]

(a) should be adjusted for more recent Au^{198} value. (624.8 and 662.2 Kev)

(b) calculated with Ba^{137} K binding energy of 37.43 Kev[4].

V CONCLUSION

The agreement between the results of the present investigation and those of other investigators is satisfactory. One may now have increased confidence in the absolute energy determinations of our electrostatic analyzer. It must be emphasized that the presence of small residual magnetic fields anywhere in the path of the electrons must be measured and corrected for according to the method discussed by Honnold and Miller.

We are planning two further checks of the analyzer. One with the Au^{198} 412 Kev line and the other with the ThC" 2.61 Mev line. The latter should be quite significant in that it would complete the bracket of the beryllium and deuterium photo thresholds.

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